TECHNICAL MEMORANDUM

SUBJECT: Estimation of Subtidal Oyster Habitat in the Northern Gulf of Mexico

DATE: September 8, 2015

TO: Marla Steinhoff, NOAA; Mary Baker, NOAA

FROM: Henry Roman, IEc and Michelle Bourassa Stahl, MBS

INTRODUCTION

Response activities from the Deepwater Horizon (DWH) spill led to mortality impacts in the subtidal zone that affected oysters of all sizes – spat (<25 millimeters (mm)), seed (between 25 and 75 mm), and market (>75 mm) (Powers et al. 2015; Grabowski et al.,2015). In order to characterize these losses, we synthesized oyster habitat (scattered shell or contiguous reef structure) percent cover data collected during various Louisiana Department of Wildlife and Fisheries (LDWF) and DWH Natural Resource Damage Assessment (NRDA) associated census and sampling activities. We formulated oyster habitat cover estimates across the northern Gulf of Mexico (GoM) study area including previously known and probable oyster habitat in Louisiana, Mississippi, Alabama and Florida waters. This technical memo describes the different LDWF surveys and NRDA studies with substrate mapping data and the process by which we estimated subtidal oyster habitat cover in the study area. This information supports the determination of oyster abundance before and after the DWH oil spill in subtidal regions (Powers et al. 2015) and the characterization of larval transport among regions in the study area (Murray et al. 2015).

METHODS

Available Data

There were three main sources of data used in the estimation (Table 1).

1. LDWF Water Bottom Assessments (Surveys) (BIO-WEST 2010a, 2010b and 2011)
2. NRDA Oyster Sampling Plans
    a. Oyster Sampling Transition Plan (NOAA 2011)
    b. 2013 Oyster Quadrat Abundance Monitoring Plan (NOAA 2013)
3. NRDA 2013 Oyster Resource Mapping Plan (BIO-WEST 2014, Bourassa Stahl *in prep.*, NOAA 2014)

Substrate Classification

All studies classified substrate into three or four categories, two representing oyster habitat and two representing non-oyster habitat (Table 2) following Louisiana Department of Wildlife protocols (LDWF 2005 and 2012). Side scan sonar methods allowed for the differentiation

between Type 3a (scattered shell) and Type 3b (contiguous oyster reef). Line intercept transect poling methods could not distinguish between types 3a and 3b and only mapped to the collective category of Type 3.

Strata Delineation

Potential oyster habitat defined by state agency biologists was identified in Alabama, the Florida panhandle, Louisiana and Mississippi. The primary oyster habitat requirement taken into account in the identification of potential oyster habitat was salinity.

The habitat was split into two main categories (strata):

1. Stratum A - mapped oyster reefs (AL, LA and MS) or known habitat (FL)
2. Stratum B - unmapped potential oyster habitat

In Louisiana, some commercially leased areas of stratum B were identified as unmapped highly probable habitat and identified as A+. Also in Louisiana, the remaining stratum B was split into sub-strata based on coastal study areas and leased/non-leased areas. In Mississippi, stratum B was split into coastal bays and open water sub-strata.

Shapefiles of these strata were either supplied by agency biologists or created specifically for NOAA, NRDA sampling plans (Table 3, NOAA 2011, 2013).

Sample Frame Definition

A sample frame of 600 x 600 meters (36 hectares) 'transition' sites was created over strata A/A+ in Louisiana and stratum A in Mississippi. Sites were mapped during the Oyster Sampling Transition Plan (NOAA 2011) or the 2013 Oyster Quadrat Abundance Monitoring Plan (NOAA 2013). Cells had to have a minimum of 25% overlap with stratum A/A+ (LA) or stratum A (MS) for membership.

A sample frame of 200 x 200 meters (4 hectares) 'mapping' sites was created over strata B in Louisiana and Mississippi and strata A and B in Alabama and Florida. Sites were mapped during the 2013 Oyster Resource Mapping Plan (NOAA 2014).

Membership in sample frames for strata A and B in Alabama and Florida was based on the location of the cell center point. Cells were then dropped from stratum A and B sample frames if center points were < 50 meters from shoreline and from stratum A sample frames if center points were < 50 meters from stratum B.

Membership in sample frames for strata B in Louisiana was based on percent leased area in the cell. Cells with > 50% leased area were assigned to lease strata sample frames and cells with < 50% leased area were assigned to non-lease strata sample frames. Cells were then dropped from

all strata sample frames if center points were < 50 meters from shoreline and if there was any overlap with stratum A/A+ sample frame cells.

Membership in sample frames for strata B in Mississippi was based on the amount of area overlap with the two sub-strata. Cells were assigned to the sub-strata with the largest area of overlap. Cells were then dropped from all strata sample frames if center points were < 50 meters from shoreline and if there was any overlap with stratum A sample frame cells.

Sample frames are shown in Figures 1 – 4.

Site Selection

Sample sites were selected from each strata sample frame using the generalized random tessellation stratified (GRTS) sampling procedure (Stevens and Olsen 1999 and 2004).

Field Methods

Survey areas and sites were sampled using either high resolution side scan sonar (Allen et al. 2005, Mazel 1985) or line intercept methods (Butler and McDonald 1983, Lucas and Seber 1977) using probing techniques.

Side scan sonar – overlapping side scan sonar imagery was completed for an entire survey area (thus considered a census) or an entire sample site following transect lines. As such, substrate classifications from side scan sonar data are based on measured area with the given substrate classification and are not statistical estimates. Corresponding substrate probing at the time of side scan sonar imagery collection and additional ground-truthing using probing and oyster dredge tows were used to assist in supervised classification of substrate from the side scan sonar imagery (BIO-WEST 2010a, 2010b, 2011 and 2014).

Line intercept - line intercept methods involved calculating the length of the intercept of the substrate along eight systematic, north/south oriented transect lines. The length of the intercept was determined by regular substrate probing along the transect lines (NOAA 2011 and 2014, Bourassa Stahl et al., in prep).

Estimation Methods

All analyses and estimates were completed using R (R Core Team 2014) unless otherwise specified.

Stratum sample frame area - not all area in the stratum sample frames created for the NRDA Oyster Sampling Plans was used in the estimation. Stratum sample frame area was adjusted to exclude any overlap with LDWF survey areas and to account for missing data due to dropped sites, selected sites unable to be mapped. The proportion of dropped sites is used to estimate the proportion of sample frame area with missing data. The proportion of dropped sites was calculated individually for each stratum sample frame except for coastal study areas (CSAs) 1N,

1S and 3 in A/A+ in Louisiana. Since site selection occurred across instead of within these CSAs, the proportion of dropped sites to estimate the proportion of stratum sample frame area with missing data was calculated across the three CSAs and applied to each CSA individually to estimate stratum sample frame area (Table 4). Final sample frame area to which we can apply estimates and make inference is calculated as the sample frame area excluding overlap with LDWF survey areas times the proportion of sites with mapping data. The final area is the area to which we can make inferences (i.e. apply estimates).

Site percent cover oyster habitat **-** unbiased site percent cover estimates of oyster habitat for sites mapped using line intercept methods were calculated by dividing the length of the intercept of oyster habitat by the length of surveyed transect lines (Butler and McDonald 1983, Lucas and Seber 1977). Percent cover estimates for sites mapped using side scan sonar were calculated as the total area of oyster habitat divided by the total site area (4 hectares).

Mean stratum percent cover oyster habitat - not all sites mapped during the NRDA Oyster Sampling Plans were used in the percent cover estimation. Sites that fell completely within an LDWF survey area and sites that fell outside of CSAs 1N, 1S and 3 for stratum A/A+ in Louisiana were dropped from the estimation. Mean stratum percent cover estimates of oyster habitat were calculated as the mean of all site percent cover estimates for sites within the stratum sample frames excluding those identified above.

Stratum area oyster habitat – stratum area oyster habitat is calculated as the final stratum area times the mean stratum percent cover oyster habitat estimate. Area estimates for LDWF survey areas were calculated as the sum of all area mapped with Type 3 substrate.

State/Gulf of Mexico area oyster habitat **-** oyster habitat area estimates were summed across strata within individual states for state estimates and across multiple states for a single estimate for the northern Gulf of Mexico.

Bootstrap confidence intervals - bootstrapping (Manly 2007) was used to estimate 90% confidence intervals (CI) for stratum percent cover and area (hectare) estimates of oyster habitat by sampling mapped sites with replacement. We calculated CIs based on the central 90% of the bootstrap distribution (the "Percentile Method") for each parameter.

RESULTS

Stratum, state and northern GoM study area subtidal oyster habitat percent cover and area estimates are presented in Table 5 along with 90% bootstrap confidence intervals.

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Figure 1. Alabama sampling frames used for the estimation of oyster habitat in the northern Gulf of Mexico.

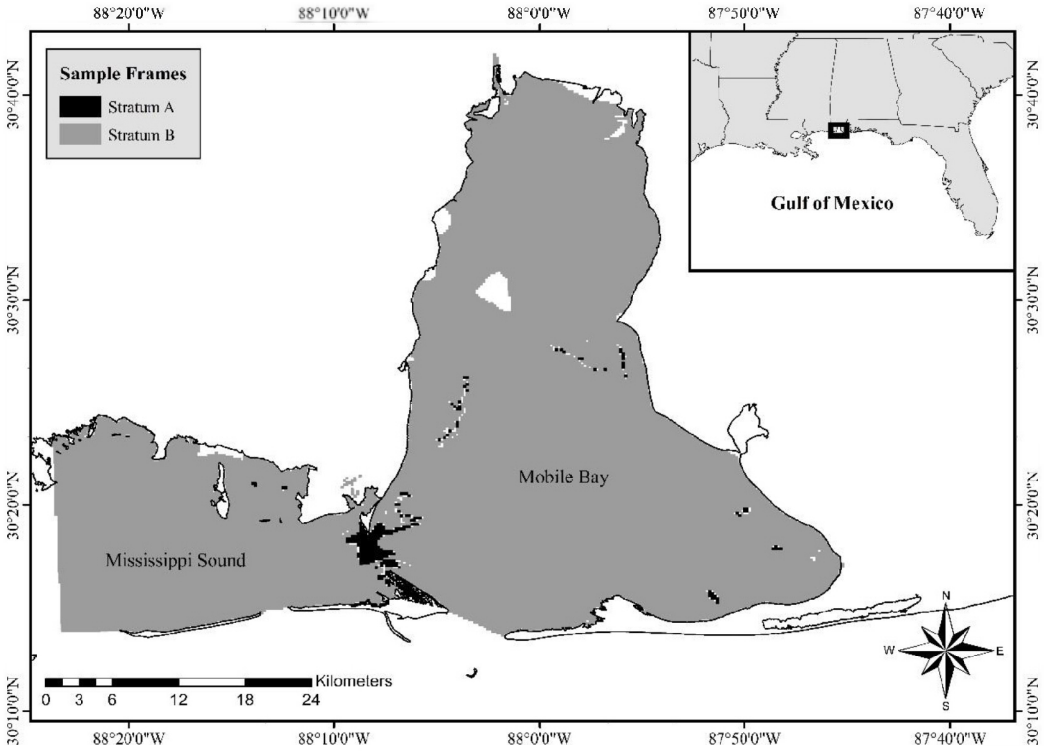

Figure 2. Florida sampling frames used for the estimation of oyster habitat in the northern Gulf of Mexico.

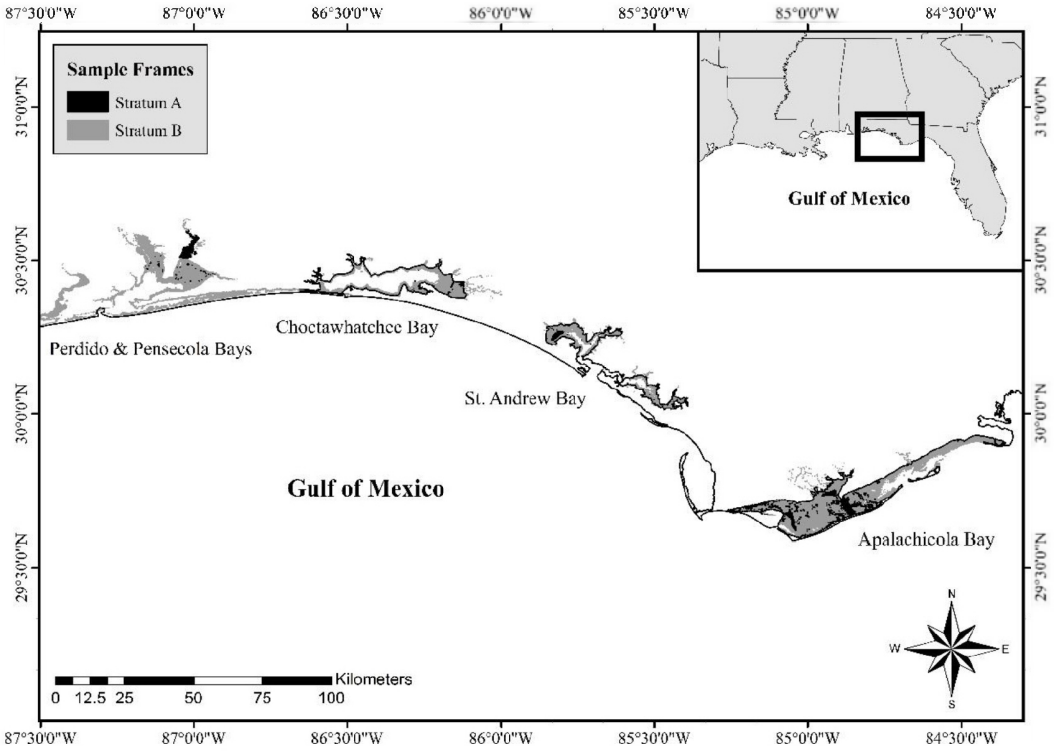

Figure 3. Louisiana survey areas and sampling frames used for the estimation of oyster habitat in the northern Gulf of Mexico. 1N, 1S, 3, 4, 5, 6 = Louisiana Department of Wildlife and Fisheries (LDWF) coastal study areas, MRBFD = Mississippi River Birds Foot Delta, MS = Mississippi Sound, BB = Black Bay, BS = Breton Sound.

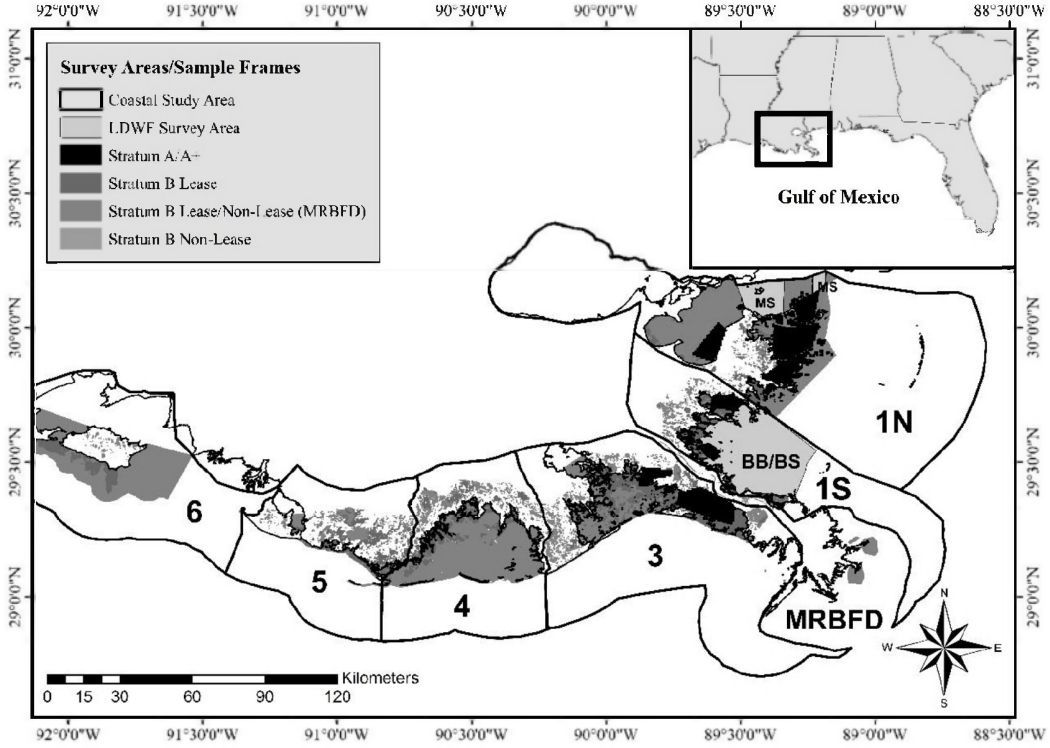

Figure 4. Mississippi sampling frames used for the estimation of oyster habitat in the northern Gulf of Mexico.

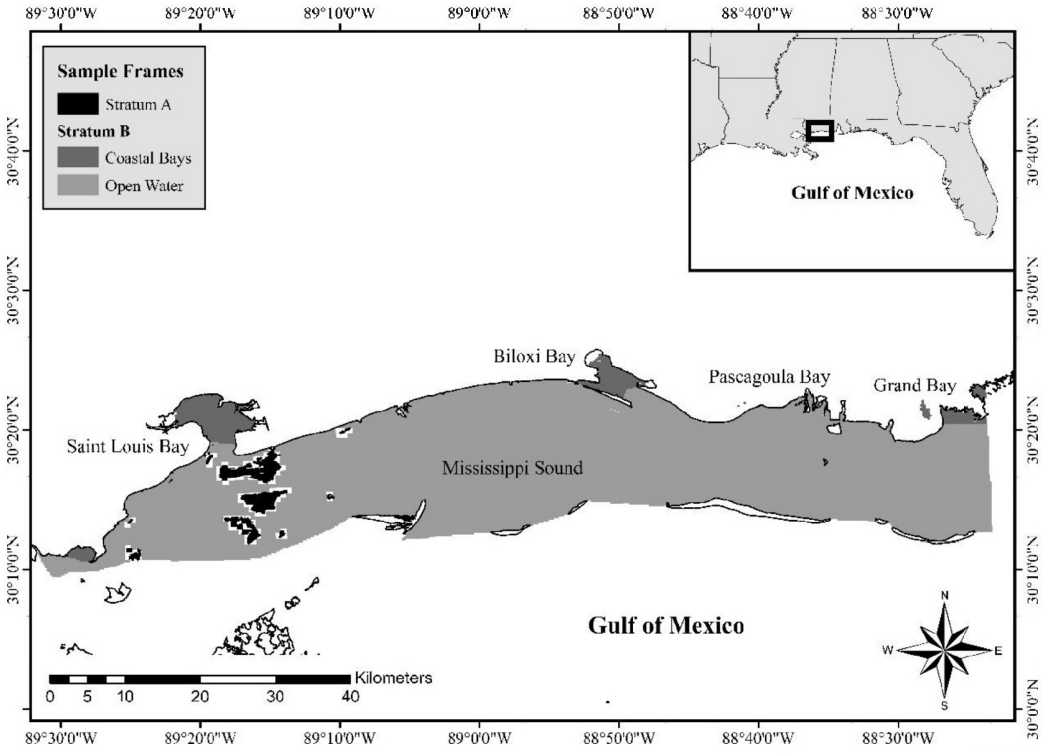

Table 1. Summary of data sources used in the estimation of subtidal oyster habitat in the northern GoM. 'sss' = side scan sonar, 'li' = line intercept, 'census' indicates a complete census of the study area, 'sample' indicates statistical sampling techniques used to select a sample of sites to map.

Agency/Study Source/Area	Map Method	Map Type	Field Crew	Mapping Dates
LDWF				
Water Bottom Assessment (Survey)				
Mississippi Sound	sss	census	BIO-WEST	August - September 2009
Black Bay	sss	census	BIO-WEST	August - October 2010
Breton Sound	sss	census	BIO-WEST	December 2010 - April 2011
NOAA, NRDA				
Oyster Sampling Transition Plan				
Louisiana	li	sample	NRDA	October - December 2010, March 2011
Mississippi	li	sample	NRDA	February - March 2011
2013 Oyster Quadrat Abundance Monitoring Plan				
Mississippi	li	sample	NRDA	August 2013
2013 Oyster Resource Mapping Plan				
Alabama	sss	sample	BIO-WEST	February 2014
Florida	sss	sample	BIO-WEST	February - March 2014
Louisiana	sss/li	sample	BIO-WEST	February - April 2014
Mississippi	sss	sample	BIO-WEST	February - March 2014

Table 2. Classifications for seafloor (water bottom) substrate types. Soft mud and shifting sand are typically unsuitable substrates for the establishment of oyster reefs. Although oysters can survive on stiff mud surfaces firm enough to support the oyster's weight, we define oyster habitat as Type 3a and 3b (collectively, Type 3) substrate.

Bottom Substrate Type	Categories	Brief Description
Type 1	Soft Mud	Soft, slushy mud – would not support small pieces of cultch material
Type 2	Moderately Firm Mud	Bottom that would support small pieces of cultch material
	Firm Mud or Sand	Compact muddy or sandy substrate
	Buried Shells	Shells buried under sediment
Type 3a	Exposed Shell	Single or scattered shells, or hard substrates such as clam shells, limestone, concrete aggregate and etc.
Type 3b	Reef	Thick shell

Table 3. Strata sources and sample frame cell size. AMRD == Alabama Marine Resources Division, FWC = Florida Fish and Wildlife Conservation Commission, LDWF = Louisiana Department of Wildlife and Fisheries and MDMR = Mississippi Department of Marine Resources. Further information on strata sources and their delineations can be found in NOAA (2011 and 2014).

State/Stratum/Coastal Study Area	Source	Cell Size (hectares)
Alabama		
A (Mapped Reefs)	AMRD – mapped oyster reef	4
B (Unmapped Potential Oyster Habitat)	AMRD – oyster management areas	4
Florida		
A (Known Habitat)	FWC – known oyster habitat	4
B (Unmapped Potential Oyster Habitat)	FWC – 12 ft depth interval in coastal bays	4
Louisiana		
LDWF Seafloor Characterization Survey Areas		
1N - Lake Borgne/Chandeleur Sound	LDWF – outlined area of interest	*NA*
1S - Black Bay/Breton Sound	LDWF – outlined area of interest	*NA*
A/A+ (Mapped Reefs/Unmapped Highly Probable Habitat)		
1N - Lake Borgne/Chandeleur Sound	LDWF – mapped oyster reefs, outlined areas	36
1S - Black Bay/Breton Sound	LDWF – mapped oyster reefs, outlined areas	36
3 - Barataria Bay	LDWF – mapped oyster reefs, outlined areas	36
B (Unmapped Potential Oyster Habitat)		
1N Lease - Lake Borgne/Chandeleur Sound	LDWF – outlined area, > 50% lease	4
1N Non-Lease - Lake Borgne/Chandeleur Sound	LDWF – outlined area, < 50% lease	4
1S Lease - Black Bay/Breton Sound	LDWF – outlined area, > 50% lease	4
1S Non-Lease - Black Bay/Breton Sound	LDWF – outlined area, < 50% lease	4
Lease & Non-Lease - Mississippi River Birds Foot Delta	LDWF – outlined area	4
3 Lease - Barataria Bay	LDWF – outlined area, > 50% lease	4
3 Non-Lease - Barataria Bay	LDWF – outlined area, < 50% lease	4
4/5 Lease - Terrebonne/Timbalier/Caillou Bays	LDWF – outlined area, > 50% lease	4
4/5 Non-Lease - Terrebonne/Timbalier/Caillou Bays	LDWF – outlined area, < 50% lease	4
6 Lease - Vermillion/Atchafalaya Bays	LDWF – outlined area, > 50% lease	4
6 Non-Lease- Vermillion/Atchafalaya Bays	LDWF – outlined area, < 50% lease	4
Mississippi		
A (Mapped Reefs)	MDMR – mapped oyster reef	36
B (Unmapped Potential Oyster Habitat)		
Coastal Bays	MDMR - outlined area, > 50% coastal bays	4
Open Water	MDMR – outlined area, > 50% open water	4

Table 4. Summary of stratum sample frame area estimation. S = selected, D = dropped, R = replaced, M = mapped. Prop. Sites is proportion of sites with mapping data which is the number of mapped sites divided by the number of selected sites (M/S). Final area is the sample frame area excluding overlap with LDWF survey areas times the proportion of sites with mapping data. The final area is the area to which we can make inferences (i.e. apply estimates).

	Area (hectares)		Number of Sites				Prop. Sites	Final Area
	Initial	Less LDWF	S[1]	D[1]	R[1]	M[1]		(hectares)
Alabama								
A (Mapped Reefs)	1,336	1,336	26	1	1	25	0.962	1,285
B (Unmapped Potential Oyster Habitat)	132,640	132,640	25	0	0	25	1.000	132,640
Florida								
A (Known Habitat)	10,004	10,004	25	0	0	25	1.000	10,004
B (Unmapped Potential Oyster Habitat)	101,172	101,172	26	1	1	25	0.962	97,281
Louisiana								
LDWF Seafloor Characterization Survey Areas								
1N - Lake Borgne/Chandeleur Sound	22,117	22,117	*NA*	*NA*	*NA*	*NA*	*NA*	22,117
1S - Black Bay/Breton Sound	96,843	96,843	*NA*	*NA*	*NA*	*NA*	*NA*	96,843
A/A+ (Mapped Reefs/Unmapped Highly Probable Habitat)								
1N - Lake Borgne/Chandeleur Sound	62,388	53,576	30	5	5	25	0.833	44,647
1S - Black Bay/Breton Sound	25,596	9,570	9	1	1	8	0.889	8,507
3 - Barataria Bay	24,444	24,444	14	3	3	11	0.786	19,206
B (Unmapped Potential Oyster Habitat)								
1N Lease - Lake Borgne/Chandeleur Sound	9,092	9,090	12	0	0	12	1.000	9,090
1N Non-Lease - Lake Borgne/Chandeleur Sound	104,444	104,070	30	1	1	29	0.967	100,601
1S Lease - Black Bay/Breton Sound	10,800	10,760	21	0	0	21	1.000	10,760
1S Non-Lease - Black Bay/Breton Sound	14,272	13,539	7	3	3	4	0.571	7,737
Lease & Non-Lease - Mississippi River Birds Foot Delta	7,188	7,188	45	16	12	29	0.644	4,632
3 Lease - Barataria Bay	36,356	36,356	34	1	1	33	0.971	35,287
3 Non-Lease - Barataria Bay	54,760	54,760	38	5	5	33	0.868	47,555
4/5 Lease - Terrebonne/Timbalier/Caillou Bays	33,316	33,316	34	1	1	33	0.971	32,336
4/5 Non-Lease - Terrebonne/Timbalier/Caillou Bays	130,316	130,316	36	3	3	33	0.917	119,456
6 Lease - Vermillion/Atchafalaya Bays	10,976	10,976	35	1	1	34	0.971	10,662
6 Non-Lease- Vermillion/Atchafalaya Bays	85,776	85,776	35	2	2	33	0.943	80,875
Mississippi								
A (Mapped Reefs)	5,004	4,961	23	5	5	18	0.783	3,883
B (Unmapped Potential Oyster Habitat)								
Coastal Bays	6,828	6,828	26	1	1	25	0.962	6,565
Open Water[3]	138,816	138,640	26	6	1	20	0.769	106,646

Table 5. Subtidal oyster habitat percent cover and area estimates. 90% bootstrap confidence intervals based on percentile method.

State/Stratum/Coastal Study Area	Percent Cover		Area (hectares)	
	Mean	90% Bootstrap CI	Area [a]	90% Bootstrap CI
Alabama				
A (Mapped Reefs)	84.7%	(75.1%, 93.1%)	1,088	(965, 1,196)
B (Unmapped Potential Oyster Habitat)	8.6%	(0.5%, 20.0%)	11,354	(637, 26,528)
Sub-total			**12,442**	**(1,754, 27,636)**
Florida				
A (Known Habitat)	20.3%	(11.2%, 30.5%)	2,033	(1,117, 3,047)
B (Unmapped Potential Oyster Habitat)	1.1%	(0.1%, 3.0%)	1,090	(78, 2,880)
Sub-total			**3,123**	**(1,504, 5,184)**
Louisiana				
LDWF Seafloor Characterization Survey Areas				
1N - Lake Borgne/Chandeleur Sound	17.8% [b]	*NA*	3,943 [b]	*NA*
1S - Black Bay/Breton Sound	16.0% [b]	*NA*	15,504 [b]	*NA*
A/A+ (Mapped Reefs/Unmapped Highly Probable Habitat)				
1N - Lake Borgne/Chandeleur Sound	14.8%	(9.3%, 20.8%)	6,583	(4,136, 9,251)
1S - Black Bay/Breton Sound	10.2%	(3.7%, 16.9%)	810	(294, 1,343)
3 - Barataria Bay	20.7%	(11.1%, 30.0%)	4,201	(2,253, 6,088)
B (Unmapped Potential Oyster Habitat)				
1N Lease - Lake Borgne/Chandeleur Sound	58.8%	(40.7%, 76.1%)	5,349	(3,702, 6,916)
1N Non-Lease - Lake Borgne/Chandeleur Sound	2.6%	(1.4%, 4.1%)	2,636	(1,457, 4,163)
1S Lease - Black Bay/Breton Sound	34.6%	(21.9%, 47.9%)	3,725	(2,352, 5,157)
1S Non-Lease - Black Bay/Breton Sound	13%	(5.0%, 21.5%)	1,006	(387, 1,663)
Lease & Non-Lease - Mississippi River Birds Foot Delta	6%	(2.8%, 9.7%)	277	(131, 450)
3 Lease - Barataria Bay	30.8%	(20.7%, 40.7%)	10,877	(7,301, 14,375)
3 Non-Lease - Barataria Bay	13%	(7.4%, 19.2%)	6,162	(3,515, 9,145)
4/5 Lease - Terrebonne/Timbalier/Caillou Bays	19%	(12.4%, 26.5%)	6,154	(4,020, 8,563)
4/5 Non-Lease - Terrebonne/Timbalier/Caillou Bays	7.9%	(1.7%, 15.4%)	9,473	(2,027, 18,427)
6 Lease - Vermillion/Atchafalaya Bays	33.9%	(24.7%, 43.9%)	3,611	(2,638, 4,683)
6 Non-Lease- Vermillion/Atchafalaya Bays	17.1%	(8.0%, 26.3%)	13,855	(6,454, 21,260)
Sub-total			**94,166**	**(81,722, 105,955)**
Mississippi				
A (Mapped Reefs)	36.2%	(23.8%, 49.1%)	1,405	(924, 1,906)
B (Unmapped Potential Oyster Habitat)				
Coastal Bays	12.2%	(6.2%, 19.6%)	801	(406, 1,289)
Open Water	5.3%	(0.3%, 14.3%)	5,674	(367, 15,274)
Sub-total			**7,880**	**(2,362, 17,395)**
Total			**117,611**	**(87,721, 155,210)**

[a] Significant digits applied at final calculation, therefore hand calculations using table values will be slightly different due to rounding error. Rounding errors are larger for larger final sample frame areas and less than 36 hectares.

[b] Percent cover and area values from LDWF Seafloor Characterization Surveys are not means as the survey areas were censused, not sampled.